Timber, Fire and Fuel Decisions: A Case Study on the Stanislaus National Forest

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PURPOSE AND ACKNOWLEDGEMENTS

THE WORK SUMMARIZED HERE WAS SPONSORED BY THE NATIONAL FUEL INVENTORY AND APPRAISAL PROJECT OF THE U.S. FOREST SERVICE. ITS PURPOSE WAS TO DETERMINE THE VALUE OF FUEL AND OTHER INFORMATION FOR MAKING DECISIONS CONCERNING FOREST FIRE MANAGEMENT, PARTICULARLY WHERE FIRE MANAGEMENT IS DIRECTLY RELATED TO TIMBER MANAGEMENT. THE STUDY REPRESENTS AN EFFORT OF ABOUT THREE MAN-MONTHS AND WAS PERFORMED AT A COST OF $20,000.

WE WISH TO ACKNOWLEDGE THE CONTRIBUTIONS AND OVERALL GUIDANCE OF PETER ROUSSOPOULOS OF THE ROCKY MOUNTAIN STATION AND DICK HARRELL OF THE PACIFIC SOUTHWEST REGIONAL OFFICE OF THE FOREST SERVICE. WE EXPECIALLY WANT TO THANK ELDON HENRY, NOEL MANCHBACH, STUART CONVERY, HAROLD SMITH, AND WILLIAM WOODS OF THE STANISLAUS NATIONAL FOREST FOR HELPING STRUCTURE THE PROBLEM AND PROVIDING DATA INPUTS.

DECISION FOCUS TAKES FULL RESPONSIBILITY FOR THE ANALYSIS, INCLUDING ANY SHORTCOMINGS.

PROBLEM DEFINITION

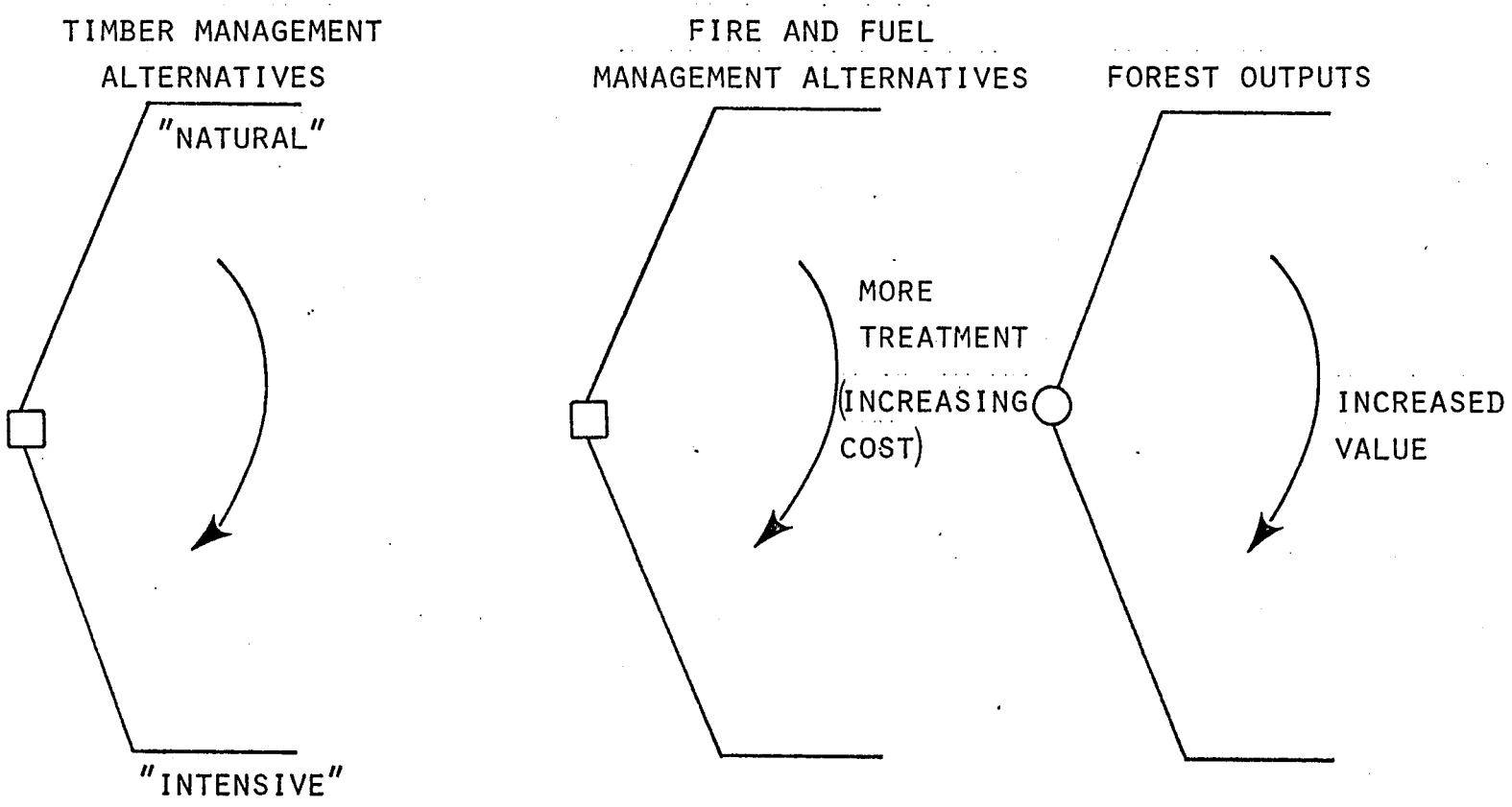
Problem Statement

A 7000-acre Ponderosa pine plantation in the Mi-wok district of the Stanislaus National Forest is reaching the point where thinning and fuel treatment decisions must be made. Fire danger is high. Timber and fire management decisions are interrelated and are complicated by the presence of uncertainty in

- yields, with and without thinning
- future stumpage prices
- fire occurrence and size
- fuel dynamics

This presentation summarizes a simple quantitative analysis of the interactions between timber, fire, and fuel decisions. It is based largely on inputs from Stanislaus National Forest personnel.

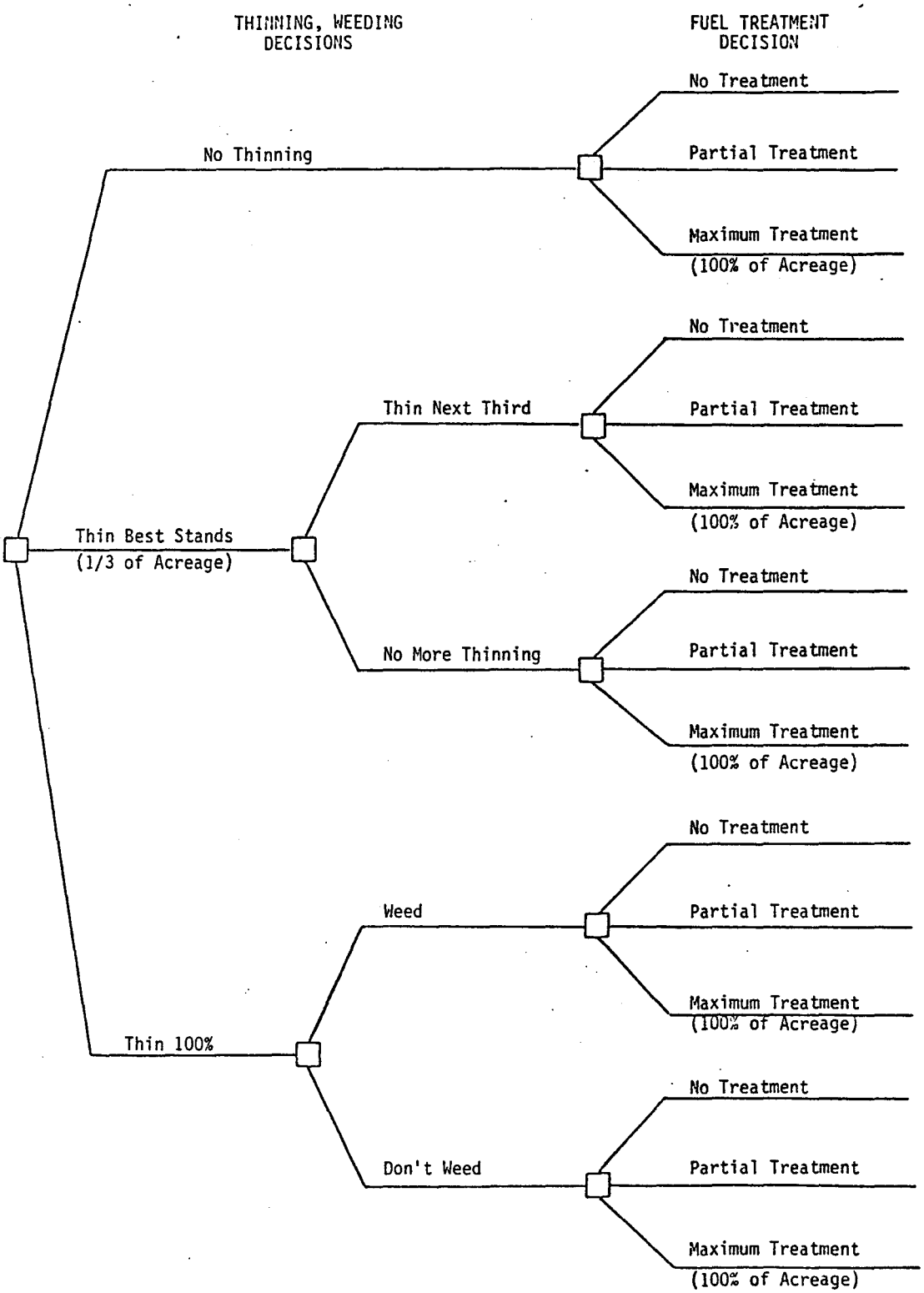
THE PROBLEM CAN BE REPRESENTED WITH A "DECISION TREE"



□ = DECISION

○ = UNCERTAINTY

BASED ON DISCUSSIONS WITH STANISLAUS PERSONNEL RESPONSIBLE FOR MANAGING BOTH TIMBER AND FIRE ASPECTS OF THE PLANTATION, A RANGE OF MANAGEMENT ALTERNATIVES WAS SPECIFIED. THESE ARE SHOWN ON THE NEXT PAGE.



Detailed Representation of Alternatives

INSIGHTS

- Several factors have a large impact on the profitability of the 7000-acre plantation:
  - ignitions
  - fire intensities
  - fire sizes
  - timber price growth
  - initial fuel loading

Although the value of the information on these variables was zero for the Stanislaus case study, it might be high in other situations.

- Other factors are less important
  - differentiation of timber yields by site classes
  - timber yields
  - suppression costs
  - natural changes in fuel loading

CONCLUSIONS AND RECOMMENDATIONS

FOR THE PLANTATION CONSIDERED HERE, THE DECISION ALTERNATIVE WITH THE HIGHEST PRESENT VALUE IS MAXIMUM THINNING PLUS WEEDING AND MAXIMUM FUEL TREATMENT. THE DECISION IS INSENSITIVE TO THE CREDIBLE CHANGES IN THE DATA VALUES.

DECISION ANALYSIS AND VALUE OF INFORMATION CALCULATIONS HAVE BEEN USED IN OTHER INSTANCES TO STUDY FUEL AND FIRE DECISIONS. THIS CASE STUDY SHOWS THAT THE SAME TECHNIQUES CAN BE EXTENDED TO INCLUDE TIMBER MANAGEMENT DECISIONS AS WELL, CAPTURING THE INTERRELATIONSHIPS AMONG FIRE AND TIMBER MANAGEMENT DECISIONS.

FURTHER WORK MIGHT INCLUDE APPLYING THE TECHNIQUE TO OTHER CASE STUDIES AND REFINING THE MODEL. A NUMBER OF MODEL IMPROVEMENTS ARE SUGGESTED ON THE FINAL PAGE OF THIS PACKAGE.

VALUE OF INFORMATION*

- o UNCERTAINTY IS HIGH FOR SEVERAL FACTORS AFFECTING THE STANISLAUS PLANTATION DECISION, BUT THE VALUE OF INFORMATION REGARDING FUEL CONDITIONS, FIRE SIZES, OR FUTURE TIMBER PRICES IS ZERO IN THIS CASE BECAUSE IT SHOULD NOT CHANGE THE DECISION.

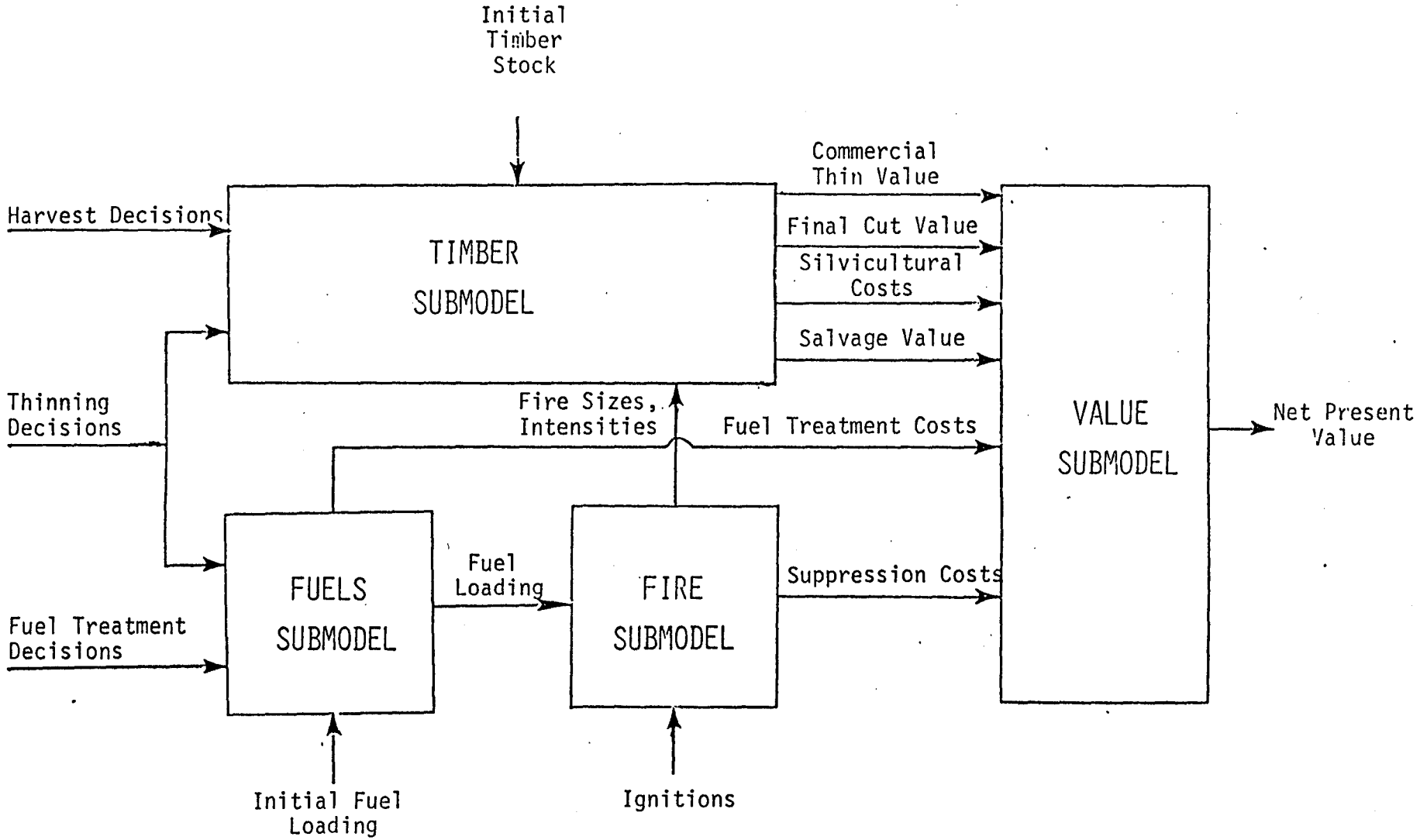
* INFORMATION COLLECTION EFFORTS AND EXPERIMENTS HAVE ECONOMIC VALUE IF THEIR EXPECTED RESULTS WILL CHANGE ACTIONS (DECISIONS) AND THUS INCREASE EXPECTED PROFIT (OR DECREASE EXPECTED LOSS).

INTEGRATING MODEL DEVELOPED FOR THIS ANALYSIS

PURPOSE OF THE MODEL

A SIMPLE MODEL INCORPORATING TIMBER GROWTH, FUEL DYNAMICS, THINNING AND FUEL TREATMENT, AND FIRE WAS CONSTRUCTED. THE MODEL

- PROVIDES AN INTEGRATING FRAMEWORK
- REQUIRES CONSISTENT COMPARISONS OF ALTERNATIVES
- PERMITS EASY SENSITIVITY ANALYSIS TO DETERMINE WHICH ISSUES ARE CRITICAL TO FIRE AND TIMBER MANAGEMENT CHOICES.



MODEL STRUCTURE

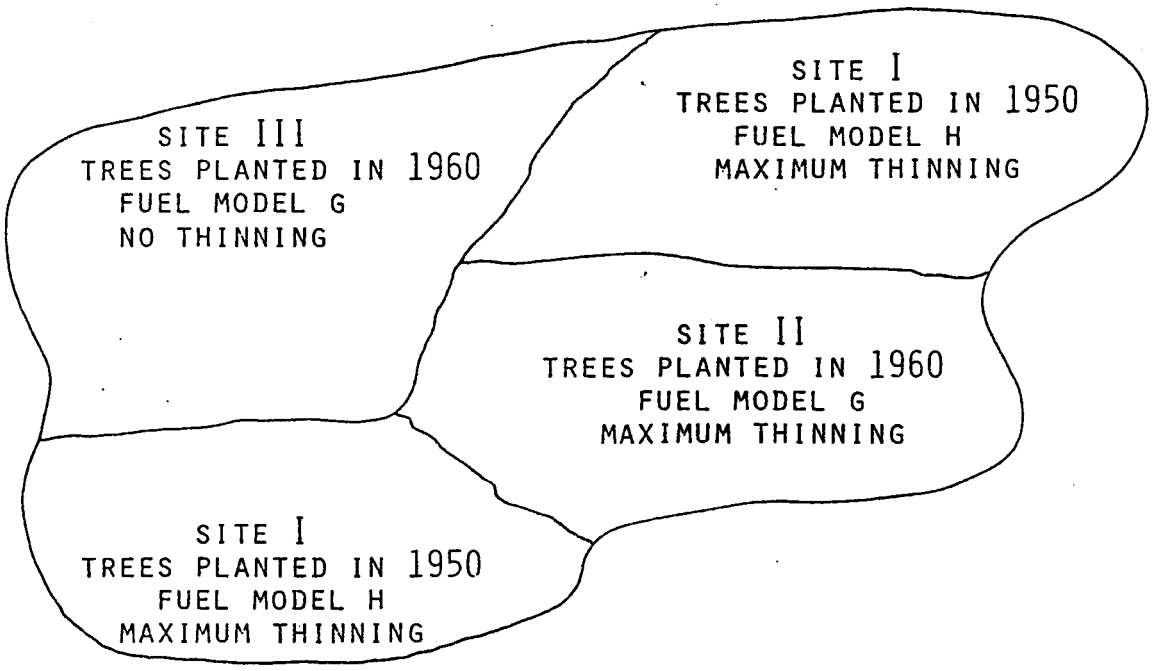
Feature	General Representation	Representation for This Study
TIME STRUCTURE	ANY NUMBER OF PERIODS, ANY PERIOD LENGTH	13 TEN-YEAR PERIODS
SITE CLASSES (TIMBER YIELDS)	ANY NUMBER OF CLASSES	SITE CLASSES 1 TO 4
THINNING POLICIES	ANY NUMBER OF POLICIES	THREE POLICIES, EACH OF WHICH CAN BE APPLIED TO PART OR ALL OF THE PLANTATION: NO THINNING COMPLETE THINNING COMPLETE THINNING PLUS WEEDING
TIMBER VOLUMES	DEPEND ON AGE, SITE CLASS, THINNING POLICY; MEASURED IN MBF/ACRE OR CUBIC FEET/ ACRE	MEASURED IN CUBIC FEET/ACRE
THINNING AND REGENERATION CUT	ANY PATTERN OF COMMERCIAL THINNING AND FINAL HARVEST	COMMERCIAL THIN AT 30,50,70 90 YEARS. FINAL HARVEST AT 110 YEARS.
STUMPAGE PRICES	UNIT PRICE INCREASES WITH TREE SIZE; PRICES INCREASE GEOMETRICALLY OVER TIME	UNIT PRICE AT ROTATION AGE TWICE THAT FOR YOUNG TREES.
FIRE INTENSITIES	ANY NUMBER OF INTENSITY LEVELS, EITHER BY FLAME LENGTH OR BTU/FT/SEC.	FOUR INTENSITY LEVELS BY FLAME LENGTH: 0'-4' 4'-6' 6'-8' 8' PLUS
FUEL MODEL	ANY NUMBER OF PATTERNS (CHANGES IN FUEL MODELS OVER TIME) AND ANY NUMBER OF FUEL MODELS	TWO PATTERNS AND THREE MODELS: H G B

REPRESENTATION OF THE FOREST LAND

- FOR EACH 10-YEAR PERIOD THE TOTAL PLANTATION AREA IS CATEGORIZED BY
  - SITE CLASS
  - WHEN TREES WERE PLANTED
  - FUEL MODEL (PATTERN)
  - THINNING POLICY

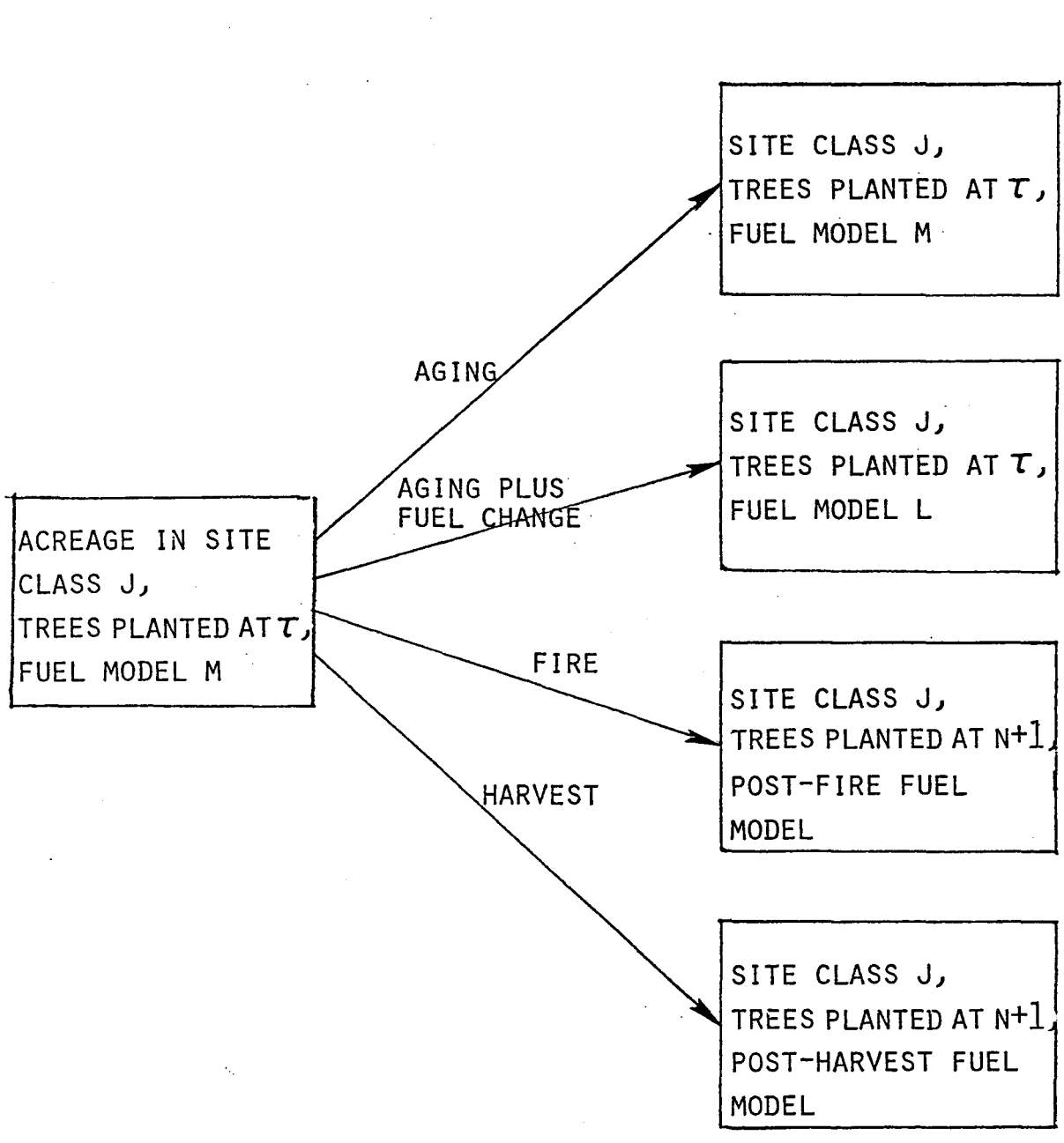
- ALL OF THE ACREAGE DESCRIBED BY THE SAME CHARACTERISTICS MAY OR MAY NOT BE CONTIGUOUS

- THE FIGURE SHOWS A MAP OF A PLANTATION FOR A SIMPLE EXAMPLE:



CHARACTERIZATION OF A HYPOTHETICAL PLANTATION IN 1990

- A SIMILAR MAP COULD BE DRAWN FOR EACH PERIOD, WHERE CHANGES WOULD OCCUR AS A RESULT OF AGING, FUEL MODEL DYNAMICS, HARVEST, AND FIRE.



POSSIBLE TRANSITIONS OVER TIME IN TREE STOCK CATEGORIZATION

MODEL ASSUMPTIONS

1) IGNITIONS ARE EQUALLY LIKELY TO OCCUR ANYWHERE IN THE PLANTATION.

2) ACREAGE SUBJECT TO FIRE OR REGENERATION CUT WILL BE REPLANTED IN THE NEXT TIME PERIOD.

3) FUEL MODEL DYNAMICS ARE DETERMINED BY THE DECISIONS MADE DURING THE FIRST PERIOD I.E., AN INITIAL DECISION ALTERNATIVE IMPLIES A PATTERN OF DECISIONS THROUGHOUT THE MODEL HORIZON; THE MODEL CANNOT ADAPT AT A LATER TIME TO CONDITIONS OTHER THAN THOSE EXPECTED WHEN THE INITIAL DECISION ALTERNATIVE WAS SELECTED.

4) FIRES OF THE LOWEST INTENSITY CAUSE NO DAMAGE OTHER THAN SUPPRESSION COSTS.

5) AFTER A FIRE SOME FRACTION OF THE TIMBER WILL BE SALVAGED. THE FRACTION DECLINES AS FIRE INTENSITY INCREASES.

6) FIRE INTENSITY, AND THUS SIZE, DEPENDS ON THE FUEL MODEL IN WHICH AN IGNITION OCCURS.

7) THINNED ACREAGE IS ALLOCATED BY AGE AND SITE CLASS BY FIRST THINNING THE OLDEST STANDS ON THE BEST SITE CLASS, THEN THE OLDEST ON THE NEXT BEST SITE CLASS, ETC. WHEN ALL OF THE OLDEST STANDS HAVE BEEN THINNED, MOVE TO THE NEXT OLDEST STANDS ON THE BEST SITE CLASS, ETC.

8) ACREAGE RECEIVING FUEL TREATMENT IS ALLOCATED BY AGE AND SITE CLASS IN THE SAME WAY: START WITH THE OLDEST STANDS ON THE BEST SITE CLASS, ETC.

Data Requirements

Fire

- Number of ignitions
- Intensity distribution
- Size distribution
- Fraction of timber salvaged after fire
- Fuel dynamics
- Hazard from fires starting outside plantation

Timber

- Rotation age
- Net volume by age and site class
- Harvest volume (thinning and regeneration) by age, site class, initial thinning policy
- Thinning and fuel treatment policies applied after fire or regeneration cut
- Initial acreage distribution by age and site class

Cost and Value

- Cost of thinning and fuel treatment policies
- Suppression cost (includes replanting, thinning, and fuel treatment for post-fire stand)
- Initial stumpage prices
- Stumpage price growth rate
- Discount rate

DEFINING A THINNING AND FUEL TREATMENT POLICY

A POLICY CONSISTS OF

- NUMBER OF ACRES THINNED (BY THINNING POLICY)
- NUMBER OF ACRES RECEIVING EACH FUEL TREATMENT POLICY
- ORDER IN WHICH THESE FUEL TREATMENT POLICIES ARE APPLIED
- FUEL MODEL CHANGES RESULTING FROM EACH POLICY

Costs and Benefits Included in Value Calculation

- Stumpage value of timber from commercial thinning and regeneration cuts
- Stumpage value of timber salvaged after fire
- Suppression cost
- Thinning and fuel treatment cost

MODEL EQUATIONS

A "CATEGORY" REFERS TO A PORTION OF THE TOTAL FOREST LAND WITH A PARTICULAR COMBINATION OF SITE CLASS, DATE AT WHICH TREES WERE PLANTED, FUEL MODEL PATTERN, AND THINNING POLICY.

BURNED ACREAGE

1) NUMBER OF IGNITIONS IN A CATEGORY AT TIME T
   = NUMBER OF IGNITIONS IN ENTIRE PLANATION
   * AREA IN CATEGORY AT TIME T/AREA OF ENTIRE PLANTATION

2) ACREAGE BURNED IN A CATEGORY AT INTENSITY J AT TIME T
   = NUMBER OF IGNITIONS IN CATEGORY AT TIME T
   * PROBABILITY THAT FIRE BURNS WITH INTENSITY J GIVEN THE FUEL MODEL FOR THIS CATEGORY
   * EXPECTED SIZE FOR FIRE OF INTENSITY J GIVEN THE FUEL MODEL AND SITE CLASS
   * (1 + RATIO OF ACREAGE BURNED FROM FIRES OF THIS INTENSITY STARTING OUTSIDE THE PLANTATION AND RUNNING IN TO ACREAGE LOST FROM FIRES STARTING INSIDE)

3) TOTAL ACREAGE BURNED AT TIME T $= \sum_{\text{ALL INTENSITIES}} \sum_{\text{ALL CATEGORIES}}$ ACREAGE BURNED BY CATEGORY AND INTENSITY

4) ACREAGE IN SITE CLASS I REQUIRING REPLANTING BECAUSE OF FIRE AT TIME T =
$\sum_{\text{ALL INTENSITIES EXCEPT THE LOWEST}} \sum_{\text{ALL CATEGORIES ON SITE CLASS I}}$ ACREAGE BURNED BY CATEGORY AND INTENSITY

Dynamics and Harvest

5) Acreage in site class I subject to regeneration cut at time T = all acreage in site class I with stands which have reached regeneration age

6) Acreage in a category at time T+1

= acreage in the category at time T

- acreage burned in the category between T and T+1 and requiring replanting

if stand did not reach age for regeneration cut at time T.

(Note that although a stand remains in the same category in successive periods, it may change fuel models. What does not change is the fuel model pattern.)

7) Acreage in site class I replanted at time T+1

= acreage in site class I requiring replanting because of fire at time T

+ acreage in site class I subject to regeneration cut at time T

Costs and Benefits

8) Value of timber harvested at time T = $\sum_{\text{ALL CATEGORIES WHICH HAVE REACHED REGENERATION AGE}}$

[area in a category

* regeneration cut yield for this site class

* unit timber price for trees of regeneration age at time T]

+ $\sum_{\text{ALL CATEGORIES AT AN AGE ALLOWING COMMERCIAL THINNING}}$

[area in a category

* commercial thin yield for this age on this site class

* unit timber price for trees of this age at time T]

9) VALUE OF TIMBER SALVAGED AT TIME T

$$= \sum_{\substack{\text{ALL INTENSITIES} \\ \text{EXCEPT THE LOWEST}}} \sum_{\text{ALL CATEGORIES}}$$

[ACREAGE BURNED BY CATEGORY AND INTENSITY
* TIMBER VOLUME FOR THE SITE CLASS AND TREE AGE IN THIS CATEGORY
* FRACTION OF TIMBER WHICH CAN BE SALVAGED IN A FIRE OF THIS INTENSITY]

10) SUPPRESSION COST AT TIME T = TOTAL ACREAGE BURNED AT TIME T * PER ACRE SUPPRESSION COST

11) INITIAL TREATMENT COST = $\sum_{\text{ALL TREATMENTS}}$

[ACRES RECEIVING EACH TREATMENT * PER ACRE TREATMENT COST]

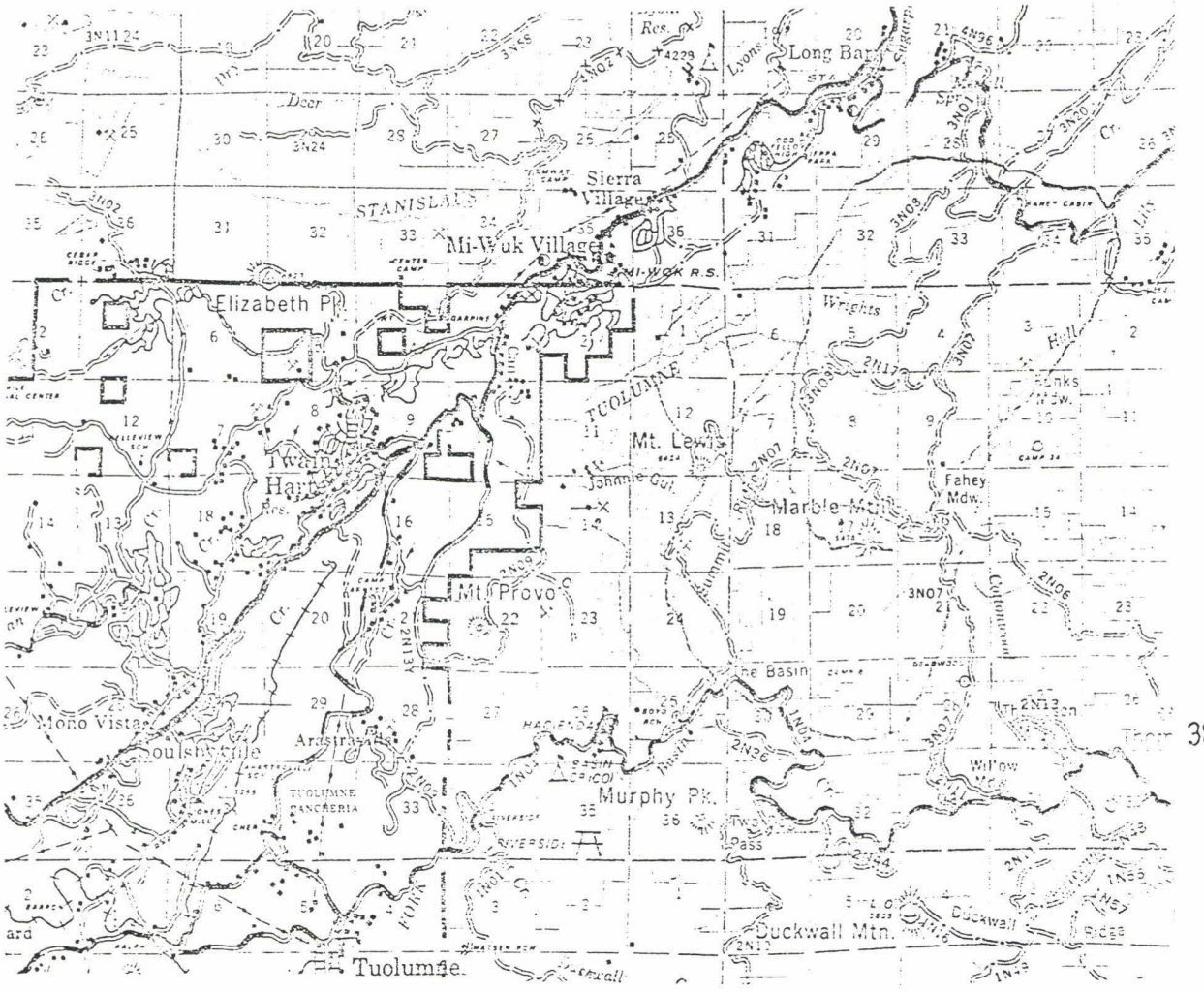
12) NET PRESENT VALUE = $\sum_{T=1}^{\text{END OF MODEL HORIZON}}$

$$\frac{\text{(VALUE OF TIMBER HARVESTED AT TIME T + VALUE OF TIMBER SALVAGED AT TIME T - SUPPRESSION COST AT TIME T)}}{(1+\text{DISCOUNT RATE})^{T*\text{TIME PERIOD LENGTH}}}$$

- INITIAL TREATMENT COST

STANISLAUS CASE STUDY DATA

THIS CASE STUDY IS FOR THE WRIGHT'S CREEK PLANTATION IN THE MI-WOK DISTRICT OF THE STANISLAUS NATIONAL FOREST IN THE SIERRA NEVADA SOUTH OF LAKE TAHOE.



THE CURRENT STATUS OF THE PLANTATION IS APPROXIMATED AS FOLLOWS:

SITE CLASS	AGE	ACRES
I	20-30	1750
I	10-20	350
II	10-20	2800
III	10-20	1400
IV	10-20	700

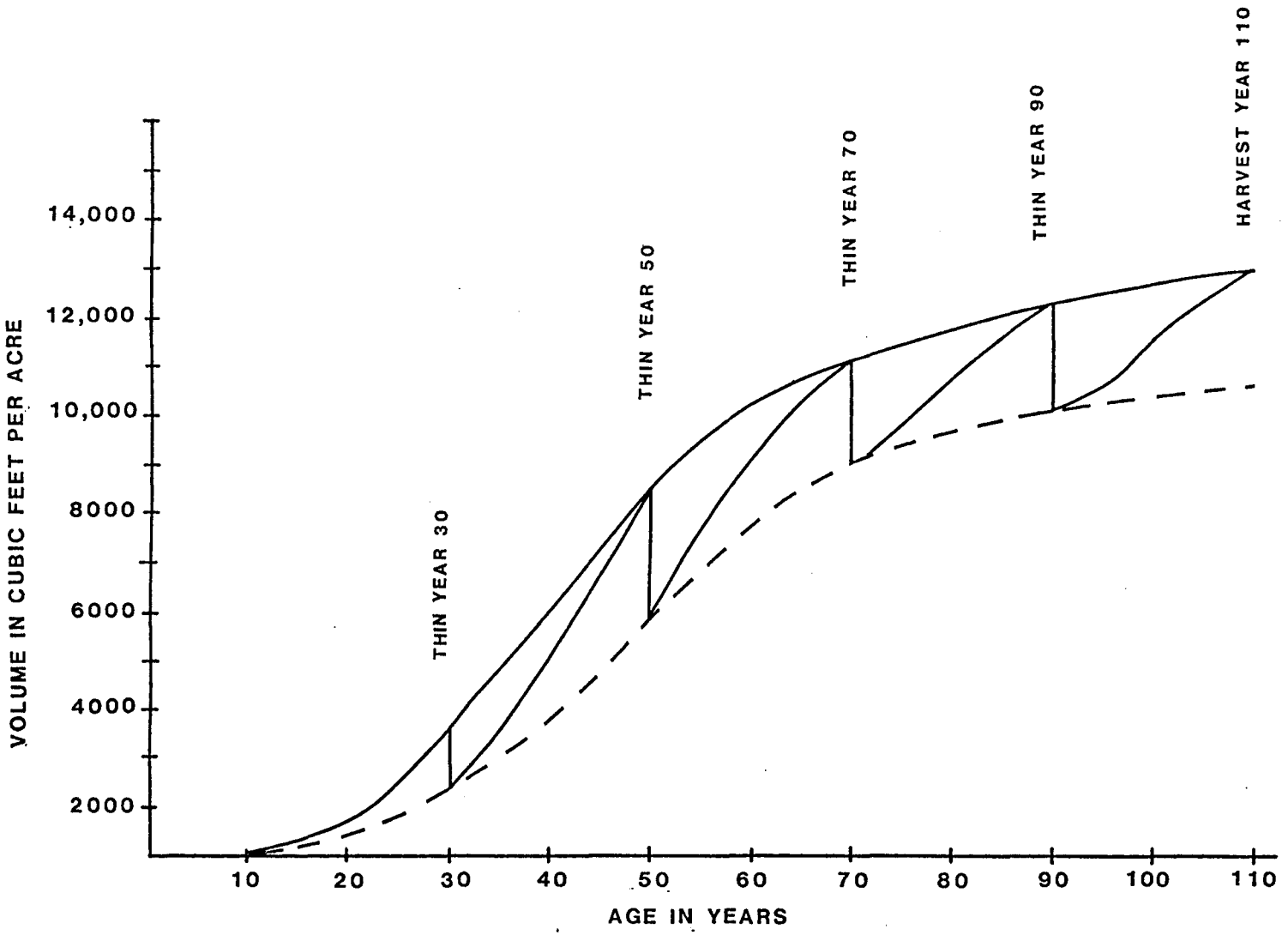
CASE STUDY ASSUMPTIONS

1) WEEDING INCREASES THE 30- AND 50-YEAR COMMERCIAL THINNING VOLUMES BY A SMALL AMOUNT AND DOES NOT AFFECT LATER VOLUMES.

2) LATER COMMERCIAL THINNINGS WILL BE MADE WHETHER OR NOT THE CURRENT THINNING IS DONE.

3) FUEL TREATMENT FOLLOWING LATER COMMERCIAL THINNINGS WILL BE SUCH THAT THE FUEL MODEL APPROPRIATE AFTER THINNING WILL BE THE SAME AS THAT BEFORE THINNING; THE COST OF SUCH TREATMENT WILL BE BORNE BY THE CONTRACTOR.

4) ACREAGE REPLANTED AFTER FIRE OR HARVEST WILL RECEIVE MAXIMUM THINNING AND FUEL TREATMENT.



GROWTH AND HARVEST FOR PONDEROSA PINE (SITE 2;INDEX 80)

Summary of Treatment Options and Costs

	No Thinning	Complete Thinning	Thinning Plus Weeding
No Fuel Treatment	0	150	200
Maximum Fuel Treatment	500	550	600

($/acre)

Maximum Fuel Treatment Consists of

- Removal of 100% of ground fuels (hand-piling and shredding with unimog--$400/acre)
- Pruning ($50/acre)
- Improvement of existing roads (shredding brush--$50/acre)

EXPECTED FIRE INTENSITIES AND SIZES

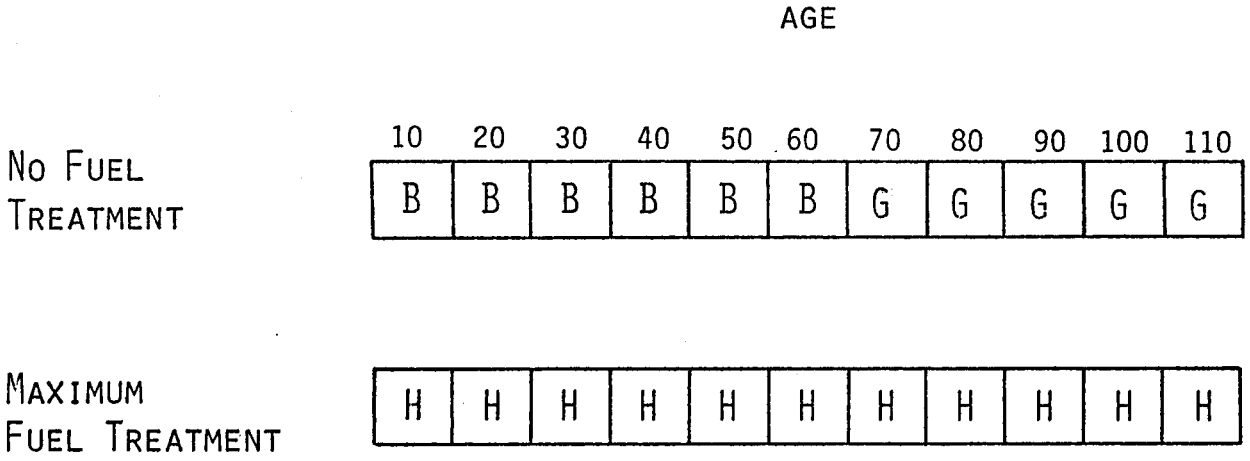
PROBABILITY THAT AN IGNITION IN A PARTICULAR FUEL MODEL WILL CAUSE A FIRE OF A PARTICULAR INTENSITY FOR THE WEATHER CONDITIONS AT THE PLANTATION (FROM FT. COLLINS FIRE BEHAV MODEL)

	INTENSITY (FLAME LENGTH)			
FUEL MODEL	0'-4'	4'-6'	6'-8'	8'+
H	1.0	0.0	0.0	0.0
G	0.84	0.16	0.0	0.0
B	0.55	0.17	0.04	0.24

EXPECTED SIZE
(ACRES FOR FIRES BURNING WITH A GIVEN INTENSITY)
(ASSESSMENTS OF STANISLAUS PERSONNEL)

INTENSITY (FLAME LENGTH)			
0'-4'	4'-6'	6'-8'	8'+
1	1000	3100	15500

FUEL MODEL DYNAMICS



RESULTS USING NOMINAL DATA VALUES

1) HISTORICAL IGNITIONS DATA, ASSESSED FIRE SIZE DISTRIBUTIONS, AND FT. COLLINS FIRE INTENSITY DISTRIBUTIONS PRODUCED BURNED ACREAGES MUCH HIGHER THAN STANISLAUS PERSONNEL BELIEVED REASONABLE; THE EXPECTED ACREAGE BURNED DURING THE FIRST 10-YEAR PERIOD WOULD BE THE ENTIRE 7000-ACRE PLANTATION. FOREST PERSONNEL FELT THAT THE EXPECTED ACREAGE BURNED IN THE PLANTATION DURING A 10-YEAR PERIOD WOULD BE 1/4 TO 1/3 OF THE ENTIRE AREA.

BASED ON DISCUSSIONS WITH FOREST PERSONNEL, THE FIRE DATA WERE MODIFIED AS FOLLOWS:

	HISTORICAL AND ASSESSED VALUES AND VALUES FROM OTHER MODELS	MODIFIED VALUES
NUMBER OF IGNITIONS PER YEAR IN PLANTATION	0.4	0.2
NUMBER OF FIRES PER YEAR STARTING OUTSIDE THE PLANTATION AND RUNNING IN	0.2	0.1

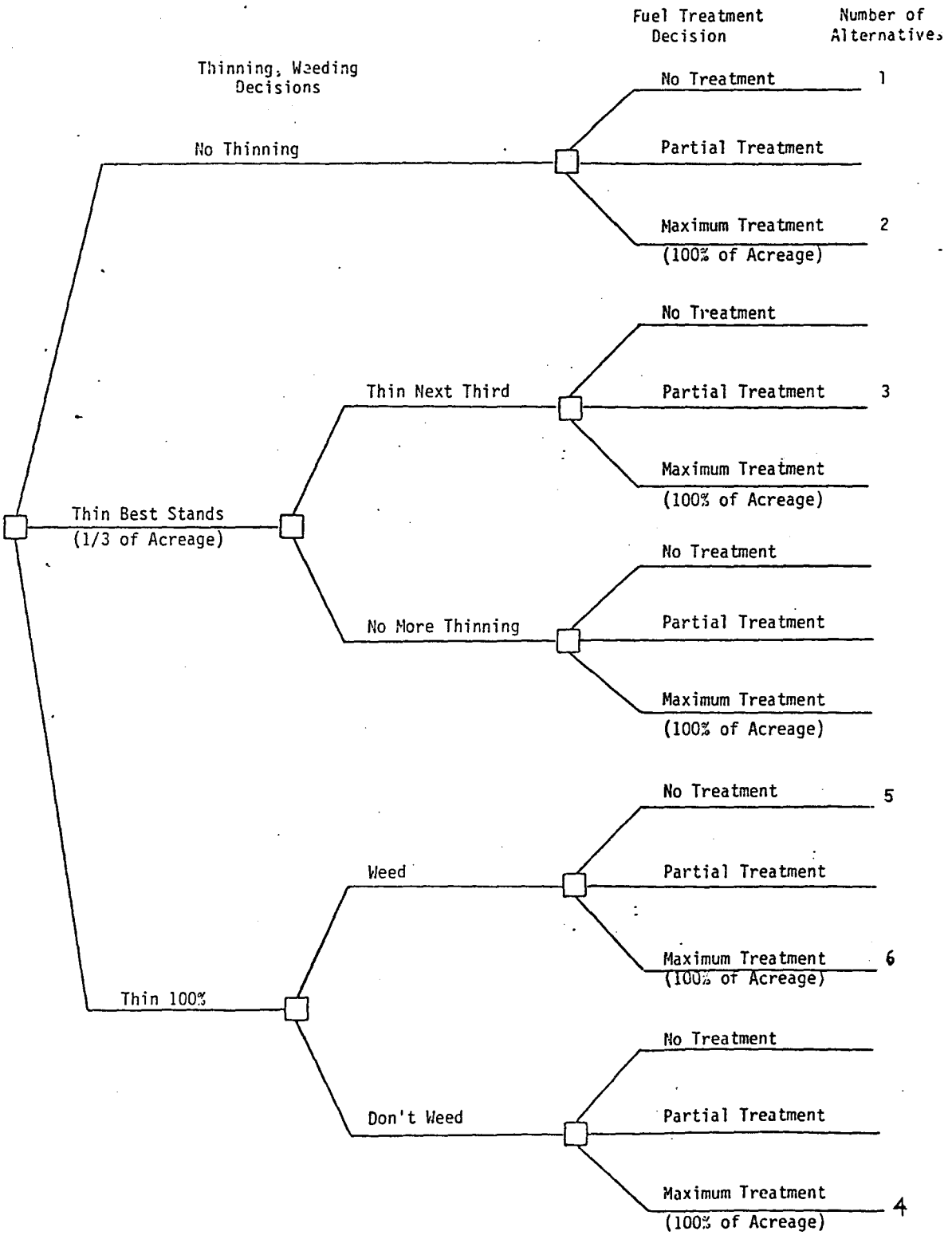
PROBABILITY THAT AN IGNITION IN A PARTICULAR FUEL MODEL WILL CAUSE A FIRE OF A PARTICULAR INTENSITY FOR THE WEATHER CONDITIONS AT THE PLANTATION (FROM FT. COLLINS FIRE BEHAV MODEL)

	INTENSITY (FLAME LENGTH)			
FUEL MODEL	0'-4'	4'-6'	6'-8'	8'+
H	1.0	0.0	0.0	0.0
G	0.84	0.16	0.0	0.0
B	0.7	0.1	0.1	0.1

EXPECTED SIZE
(ACRES FOR FIRES BURNING WITH A GIVEN INTENSITY)
(ASSESSMENTS OF STANISLAUS PERSONNEL)

INTENSITY (FLAME LENGTH)			
0'-4'	4'-6'	6'-8'	8'+
1	500	2000	5000

2) To save time and money, only the 6 alternatives indicated on the next page were considered instead of the entire set of 15. These 6 alternatives "span" the entire range, and the inclusion of additional alternatives should make no difference. (The other alternatives were tried for the base case and had lower present values than the preferred alternative.) For forests with greater differences among site classes or lower fire danger, one of the intermediate alternatives not considered here might be preferred.



ALTERNATIVES CONSIDERED

BASE CASE RESULTS

1) THE PREFERRED ALTERNATIVE - THE ONE WITH THE HIGHEST NET PRESENT VALUE - IS MAXIMUM THINNING AND WEEDING PLUS MAXIMUM FUEL TREATMENT.

2) FUEL TREATMENT WITHOUT THINNING IS MORE VALUABLE THAN THINNING WITHOUT FUEL TREATMENT, BECAUSE MUCH OF THE BENEFIT OF THINNING WILL BE LOST ON ACCOUNT OF THE HIGH FIRE DANGER.

3) THE VALUE OF THINNING AND WEEDING IS GREATER WHEN MAXIMUM FUEL TREATMENT IS DONE THAN WHEN NO FUEL TREATMENT IS DONE.

BASE CASE MODEL RESULTS

ALTERNATIVE	EXPECTED ACREAGE BURNED DURING FIRST TEN YEARS	EXPECTED TIMBER HARVESTED OVER 130 YEARS (10^6 FT.^{3})	COMPONENTS OF PRESENT VALUE (MILLION DOLLARS) HARVEST VALUE	SALVAGE VALUE	SUPPRESSION COST	INITIAL THINNING AND FUEL TREATMENT COST	NET PRESENT VALUE
1) NO THINNING, NO FUEL TREATMENT	2252	102	9.4	3.5	2.5	0.0	10.5
2) NO THINNING, MAXIMUM FUEL TREATMENT	3	144	19.9	0.0	0.0	2.8	17.1
3) PARTIAL THINNING, PARTIAL FUEL TREATMENT	1127	130	17.2	10.9	1.2	1.7	15.4
4) MAXIMUM THINNING, MAXIMUM FUEL TREATMENT	3	148	21.8	0.0	0.0	3.1	18.7
5) MAXIMUM THINNING, AND WEEDING NO FUEL TREATMENT	2252	106	11.0	3.5	2.5	1.1	11.0
6) MAXIMUM THINNING AND WEEDING, MAXIMUM FUEL TREATMENT	3	151	22.5	0.0	0.0	3.4	19.2

SENSITIVITY ANALYSIS

SENSITIVITY ANALYSIS WAS PERFORMED TO DETERMINE HOW THE DECISION WOULD CHANGE WHEN CHANGES IN THE DATA WERE MADE.

Sensitivity Analysis Results

- Large differences in acreage burned among alternatives
- Smaller differences in net present value among alternatives -- increased harvest value partially offset by cost of thinning and fuel treatment
- Decision insensitive to data changes used here --in all cases maximum thinning plus weeding combined with maximum fuel treatment is the preferred alternative

SENSITIVITY ANALYSIS
(NET PRESENT VALUES IN MILLIONS OF DOLLARS)

	NO THINNING, NO FUEL TREATMENT	NO THINNING, MAXIMUM FUEL TREATMENT	PARTIAL THINNING, PARTIAL FUEL TREATMENT	MAXIMUM THINNING, MAXIMUM FUEL TREATMENT	MAXIMUM THINNING & WEEDING, NO FUEL TREATMENT	MAXIMUM THINNING & WEEDING MAXIMUM FUEL TREATMENT
1) BASE CASE	10.5	17.1	15.4	18.7	11.0	19.2
2) HIGHER IGNITIONS	7.5	17.1	14.0	18.7	7.2	19.2
3) LOWER IGNITIONS	14.1	17.1	17.0	18.7	15.0	19.2
4) FIRE SIZES AT 10%	8.3	17.1	14.5	18.7	8.5	19.2
5) FIRE SIZES AT 50%	6.9	17.1	13.8	18.7	6.1	19.2
6) LOWER B INTENSITIES	13.7	17.1	16.8	18.7	14.6	19.2
7) HIGHER B INTENSITIES	7.3	17.1	14.0	18.7	7.1	19.2
8) HIGHER SUPP. COST	9.2	17.1	14.7	18.7	9.8	19.2
9) LOWER SUPP. COST	11.7	17.1	16.0	18.7	12.2	19.2
10) HIGHER TREATMENT COST	10.5	14.3	13.7	15.6	9.9	15.8
11) LOWER TREATMENT COST	10.5	18.5	16.2	20.2	11.5	20.8

SENSITIVITY ANALYSIS (CONTINUED)
(NET PRESENT VALUES IN MILLIONS OF DOLLARS)

	NO THINNING, NO FUEL TREATMENT	NO THINNING, MAXIMUM FUEL TREATMENT	PARTIAL THINNING, PARTIAL FUEL TREATMENT	MAXIMUM THINNING, MAXIMUM FUEL TREATMENT	MAXIMUM THINNING & WEEDING, NO FUEL TREATMENT	MAXIMUM THINNING & WEEDING, MAXIMUM FUEL TREATMENT
12) HIGH PRICE GROWTH	5.1	7.3	6.5	7.5	5.2	7.6
13) LOW PRICE GROWTH	2.6	3.9	4.2	5.2	2.8	5.4
14) SAME PRICE FOR ALL SIZES	14.2	19.8	19.3	22.8	15.8	23.6
15) HIGHER SALVAGE	12.9	17.1	16.1	18.7	13.4	19.2
16) LOWER SALVAGE	9.2	17.1	14.5	18.7	9.7	19.2
17) HIGHER YIELDS	11.0	18.5	16.4	20.1	11.5	20.6
18) LOWER YIELDS	10.0	15.7	14.3	17.3	10.5	17.8
19) HIGHER WEEDING EFFECT	10.7	17.1	15.5	18.7	11.5	19.9
20) LOWER WEEDING EFFECT	10.4	17.1	15.3	18.7	10.7	18.8
21) SWITCH TO G TWO PERIODS EARLIER	13.2	17.1	16.3	18.7	13.8	19.2
22) SWITCH TO G TWO PERIODS LATER	9.6	17.1	15.1	18.7	10.1	19.2

SENSITIVITY ANALYSIS (CONTINUED)
(NET PRESENT VALUES IN MILLIONS OF DOLLARS)

	NO THINNING, NO FUEL TREATMENT	NO THINNING, MAXIMUM FUEL TREATMENT	PARTIAL THINNING, PARTIAL FUEL TREATMENT	MAXIMUM THINNING, MAXIMUM FUEL TREATMENT	MAXIMUM THINNING & WEEDING, NO FUEL TREATMENT	MAXIMUM THINNING & WEEDING MAXIMUM FUEL TREATMENT
23) REDUCE INTENSITIES TO GET SAME BURN AS BASE CASE	9.7	17.1	15.1	18.7	10.1	19.2
24) REDUCE SIZES TO GET SAME BURN AS BASE CASE	9.9	17.1	15.2	18.7	10.4	19.2
25) REDUCE IGNITION TO GET SAME BURN AS BASE CASE	10.4	17.1	15.4	18.7	11.0	19.2
26) ROTATION = 100	12.1	19.9	17.7	21.5	12.6	22.0
27) REDUCED SIZE WITH PARTIAL TREATMENT	10.5	17.1	18.1	18.7	11.0	19.2
28) 50% G	14.9	17.1	18.8	18.7	15.9	19.2
29) 10% ON SIZES	12.8	17.1	16.4	18.7	13.7	19.2
30) B SWITCHES TO H	13.8	17.1	16.5	18.7	14.4	19.2

DEFINITION OF SENSITIVITIES

1) BASE (0.2 IGNITIONS/YEAR,
FIRESIZE DISTRIBUTION = 1/500/2000/5000,
INTENSITY DISTRIBUTION = 0.7/0.1/0.1/0.1,
SUPPRESSION COST = $800/ACRE, TIMBER PRICE GROWTH AT 2% PER YEAR)

2) HIGHER IGNITIONS (0.4/YEAR)

3) LOWER IGNITIONS (0.1/YEAR)

4) FIRE SIZES AT TENTH PERCENTILE OF ASSESSED DISTRIBUTION (1/500/1250/9000)

5) FIRE SIZES AT MEDIAN OF ASSESSED DISTRIBUTION (1/1000/3100/15500)

6) LOWER INTENSITIES (0.8/0.1/0.05/0.05)

7) HIGHER INTENSITIES (0.548/0.168/0.042/0.242)

8) HIGHER SUPPRESSION COST (1200)

9) LOWER SUPPRESSION COST (400)

10) HIGHER TREATMENT COST (ALL THINNING AND FUEL TREATMENT COSTS DOUBLED)

11) LOWER TREATMENT COST (ALL THINNING AND FUEL TREATMENT COSTS HALVED)

12) Higher timber price growth (4% annual)

13) Lower timber price growth (prices constant)

14) Same timber price for all ages of trees ($0.66/cubic foot)

15) Higher salvage fraction after fire (80% of value for 4'-6' flame length, 70% for 6'-8', 60% for 8' +)

16) Lower salvage fraction after fire (40% for 4'-6', 30% for 6'-8', 20% for 8' +)

17) Higher yields (all yields after age 50 years increased 10%)

18) Lower yields (all yields after age 50 years decreased 10%)

19) Higher weeding effect (weeding increases 30 and 50 year yields by 20%)

20) Lower weeding effect (weeding increases 30 and 50 year yields by 5%)

21) Faster fuel model dynamics ("B" switches to "G" after 50 years)

22) Slower fuel model dynamics ("B" switches to "G" after 90 years)

23,24,25) ALTERNATIVE SETTINGS OF IGNITIONS, INTENSITIES, FIRE SIZES WHICH LEAD TO SAME ACREAGE BURNED AS BASE CASE

26) REDUCED ROTATION AGE (100 YEARS)

27) PARTIAL TREATMENT REDUCES EXPECTED FIRE SIZES (TREATING 50% OF AREA TO "H" REDUCES FIRE IN "B" BY 75%)

28) PLANTATION INITIALLY 50% "B" AND 50% "G"

29) REDUCE FIRE SIZES FROM MEDIAN TO TENTH PERCENTILE

30) FUEL TREATMENT IMMEDIATELY FOLLOWING FIRST COMMERCIAL THIN CONVERTS "B" FUEL MODEL TO "H"

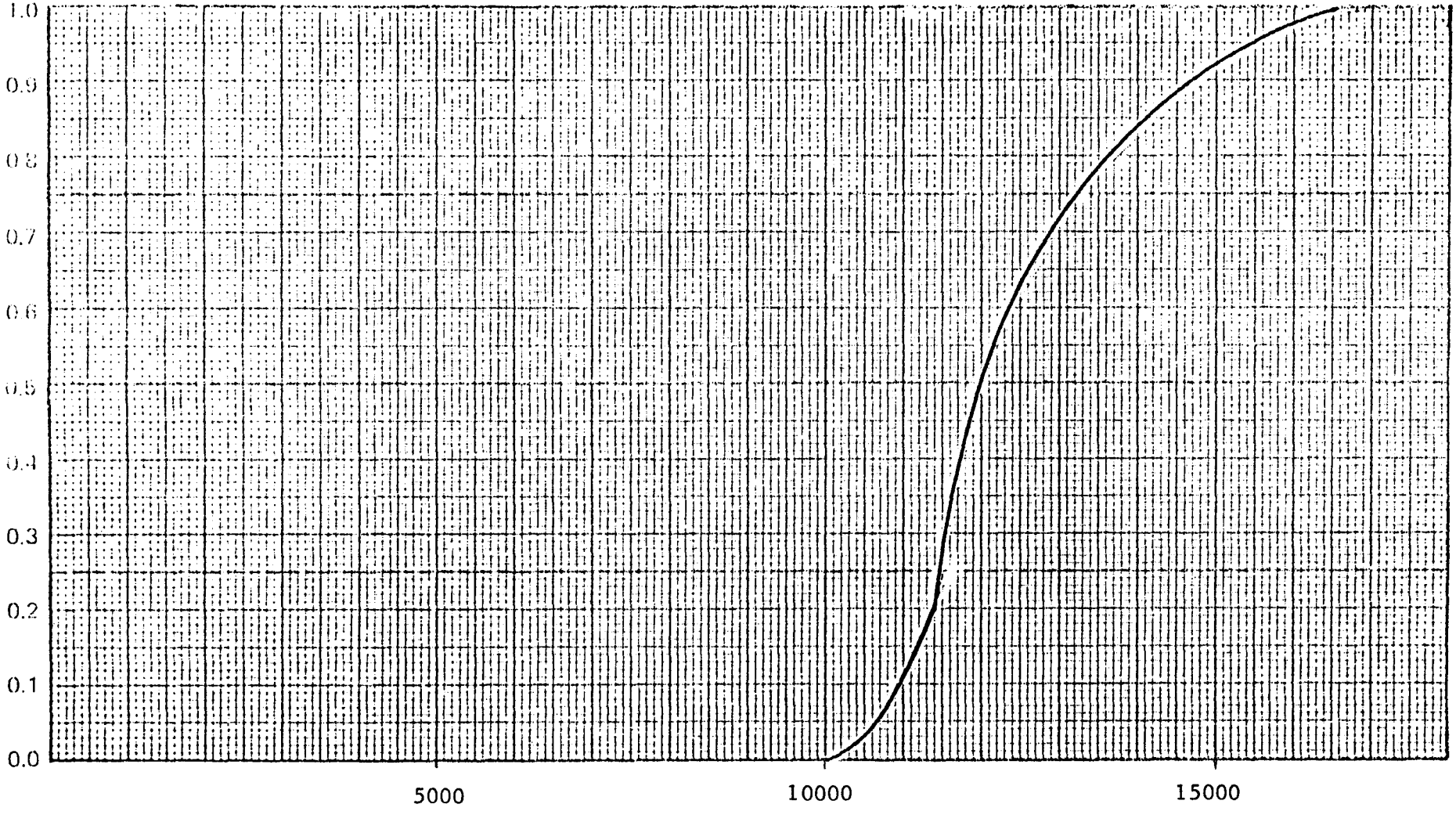
EXAMPLES OF PROBABILITY DISTRIBUTIONS ASSESSED WITH STANISLAUS PERSONNEL AND USED IN THE SENSITIVITY ANALYSIS.

FIRE SIZE FOR A FIRE STARTING IN THE PLANTATION AND BURNING WITH 6' - 8' FLAME LENGTH:

SIZE (ACRES)	PROBABILITY
1250	0.2
3100	0.6
4500	0.2

TIMBER VOLUME ON SITE CLASS II AT AGE 110 YEAR (CUMULATIVE DISTRIBUTION SHOWN ON NEXT PAGE)

VOLUME (CUBIC FEET PER ACRE)	PROBABILITY
11,200	0.2
12,000	0.6
14,000	0.2



CUMULATIVE DISTRIBUTION FOR TIMBER VOLUME (FT^3/ACRE) AT ROTATION (110 YEARS) ON SITE CLASS II (INDEX 80)

FUEL TREATMENT AFTER COMMERCIAL THINNING

ONE OF THE ASSUMPTIONS FOR THIS CASE STUDY IS THAT FUEL TREATMENT FOLLOWING LATER COMMERCIAL THINNINGS WILL BE SUCH THAT THE FUEL MODEL APPROPRIATE AFTER THINNING WILL BE THE SAME AS THAT BEFORE THINNING.

SENSITIVITY 30 SHOWS THE EFFECT OF RELAXING THIS ASSUMPTION AND ASSUMING INSTEAD THAT THE "B" FUEL MODEL AREAS WILL BE TREATED TO "H" FOLLOWING THE 50-YEAR COMMERCIAL THIN. IT CAN BE SEEN FROM THE TABLE THAT CHANGING THIS ASSUMPTION DOES NOT CHANGE THE PREFERRED ALTERNATIVE. THIS IS BECAUSE FIRE LOSSES ARE SO HIGH IN THE 20 TO 30 YEARS BEFORE THE "B" AREAS BECOME "H" THAT IT STILL PAYS TO DO MAXIMUM TREATMENT.

A HYPOTHETICAL EXAMPLE WHERE THE DECISION IS SENSITIVE AND NEW INFORMATION HAS POSITIVE VALUE

Consider another 7000 acre plantation with lower fire danger and less information on fuel loading than the Stanislaus plantation:

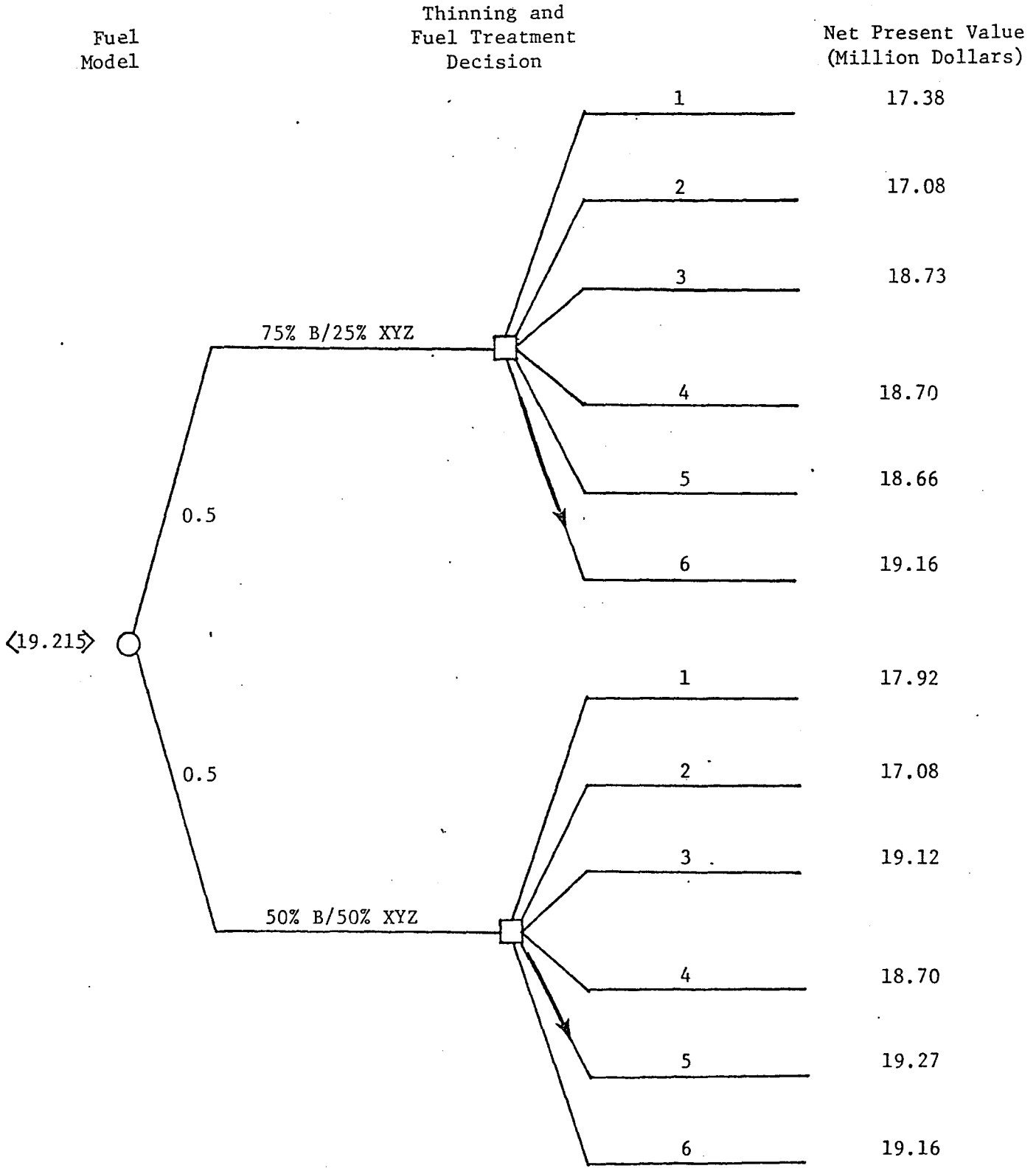
1) Expected fire sizes are the <u>same</u> as those assessed for the Stanislaus plantation (1,1000,3100, and 15500 acres for the four intensity levels).

2) The expected number of ignitions is <u>lower</u> (0.1 per year plus 0.05 fires per year running in from outside the plantation).

3) The probability of high intensity (6' and higher flame length) fires is much lower than for the Stanislaus plantation (0.8, 0.18, 0.01, and 0.01 for the four intensity levels).

4) The forest staff is uncertain which fuel models best represent the area; they believe that there is a 50% chance that 0.75 of the area is a "B" fuel model and 0.25 is in another fuel model "XYZ", which has intensity distribution 0.9, 0.1, 0.0, and 0.0, and a 50% chance that the area is equally divided between the two fuel models.

WHAT IF THE UNCERTAINTY ON FUEL LOADING COULD BE RESOLVED BEFORE THE DECISION WERE MADE?



VALUE OF INFORMATION

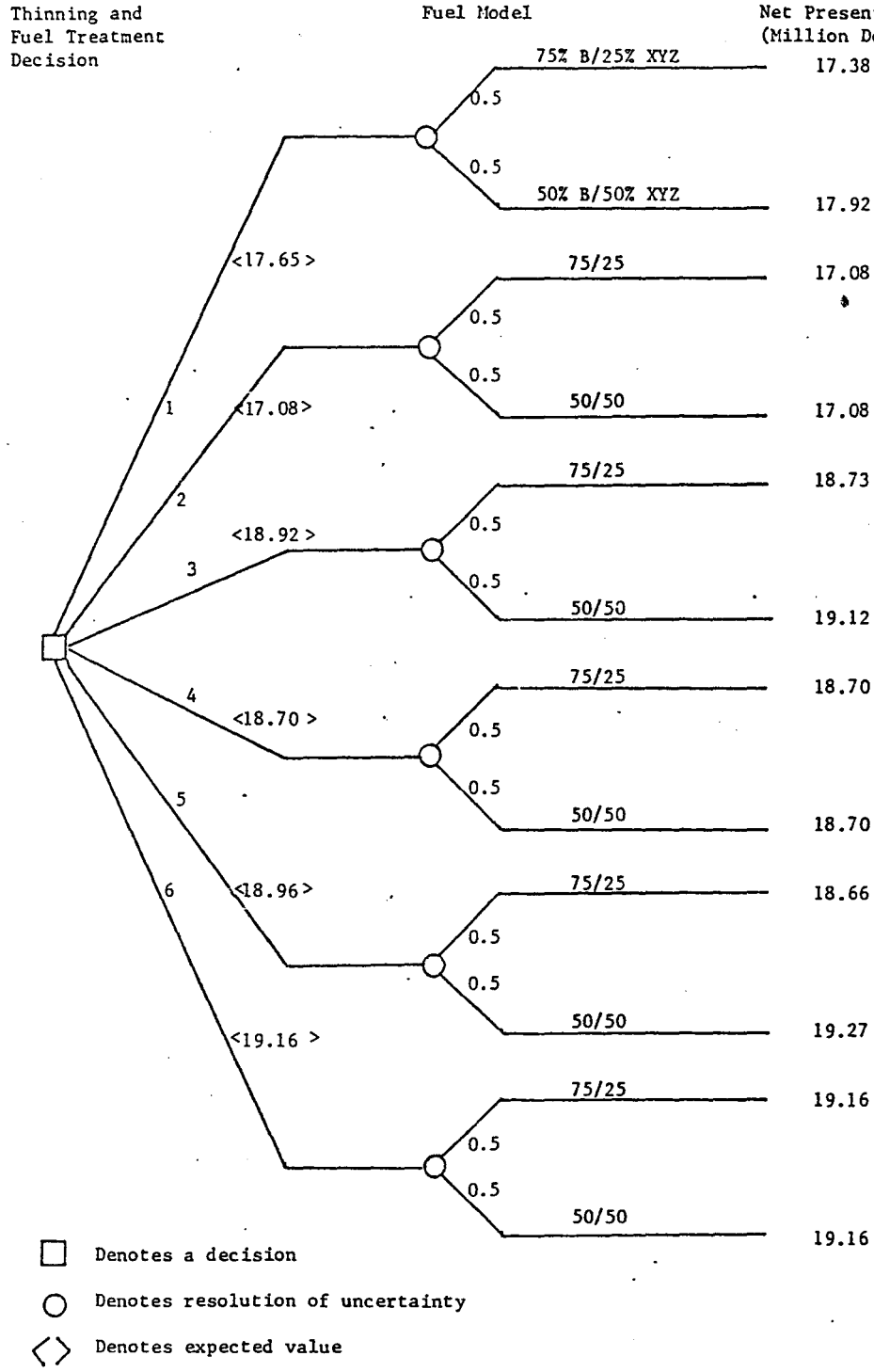
IF THE FUEL MODEL DISTRIBUTION IS 75/25, THEN THE BEST DECISION IS 6, MAXIMUM THINNING AND WEEDING PLUS MAXIMUM FUEL TREATMENT. IF THE FUEL LOADING IS 50/50, THEN THE BEST DECISION IS 5, MAXIMUM THINNING AND WEEDING WITH NO FUEL TREATMENT.

THE EXPECTED VALUE HAS INCREASED FROM 19.16 MILLION DOLLARS TO 19.215 MILLION DOLLARS. THUS PERFECT INFORMATION ON FUEL MODEL DISTRIBUTION IS WORTH 19.215-19.16 = 0.055 MILLION DOLLARS ($55,000).

THIS CORRESPONDS TO ABOUT $8/ACRE. THE DIFFERENCE IN EXPENDITURE BETWEEN ALTERNATIVES 5 AND 6 IS $400/ACRE.

KEEP IN MIND THAT $8/ACRE IS THE EXPECTED VALUE OF PERFECT INFORMATION; IT REPRESENTS AN UPPER BOUND ON EXPENDITURE FOR ACTIVITIES INTENDED TO REDUCE UNCERTAINTY ON FUEL MODEL DISTRIBUTION.

IF WE CONSIDER ONLY THE SAME SIX ALTERNATIVES,
THE DECISION TREE IS



AND THE DECISION WITH THE HIGHEST EXPECTED NET PRESENT VALUE IS NUMBER 6, MAXIMUM THINNING AND WEEDING PLUS MAXIMUM FUEL TREATMENT.

POSSIBLE MODEL IMPROVEMENTS

1) Uneven-aged stands/selective cutting

2) Reduction in pre-suppression cost as a result of fuel treatment

3) Non-timber resource values

4) Non-fire impacts of thinning and fuel treatment on timber (insects, disease)

5) Costs of replanting, thinning, fuel treatment after harvest

6) Fire protection effects on number of ignitions or expected fire sizes

7) Relationship between resistance to control (affects fire size) and fuel treatment

8) Change in fire sizes given partial treatment

9) Multiple fuel model patterns with no treatment